

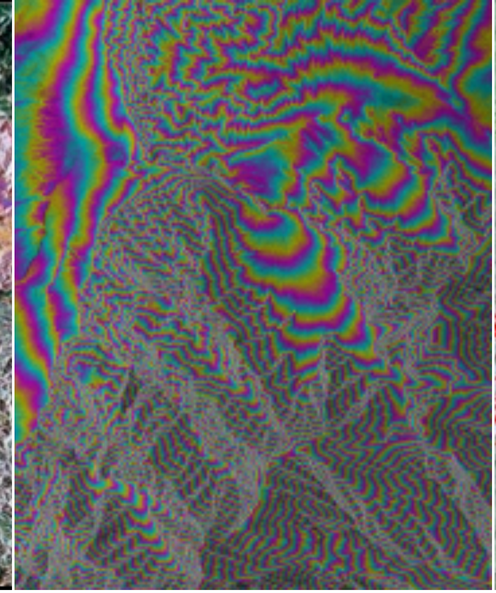


Impact of Gaps in the NASA-ISRO SAR Mission Swath

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EUSAR 2018
Aachen, Germany
June 2018

Jet Propulsion Laboratory
California Institute of Technology

Outline

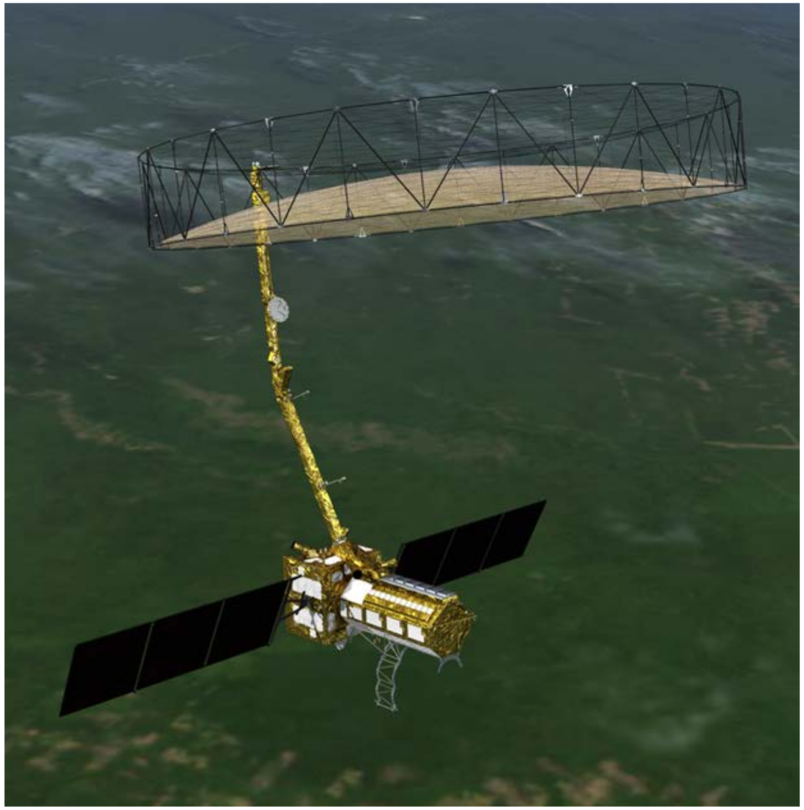
- NISAR Overview
- The Gap Problem
- Science performance versus Imaging Performance
- Summary & Mitigation Strategies

NASA-ISRO SAR (NISAR) Mission

Jet Propulsion Laboratory
California Institute of Technology

Solid Earth, Ecosystems, Cryosphere Science and Applications Mission

NISAR Characteristic:	Enables:
L-band (24 cm wavelength)	*Low temporal decorrelation and foliage penetration*
S-band (9 cm wavelength)	*Sensitivity to lighter vegetation*
SweepSAR technique with Imaging Swath > 240 km	*Global data collection*
*Polarimetry (Single/**Dual**/Quad)*	*Surface characterization and biomass estimation*
12-day exact repeat	*Rapid Sampling*
3 – 10 meters mode-dependent SAR resolution	*Small-scale observations*
Pointing control < 273 arcseconds	*Deformation interferometry*
Orbit control < 500 meters	*Deformation interferometry*
***L**/**S**-band > **50**/**10**% observation duty cycle*	*Complete land/ice coverage*
Left/Right pointing capability	*Polar coverage, north and south*



Planned Launch: December 2021

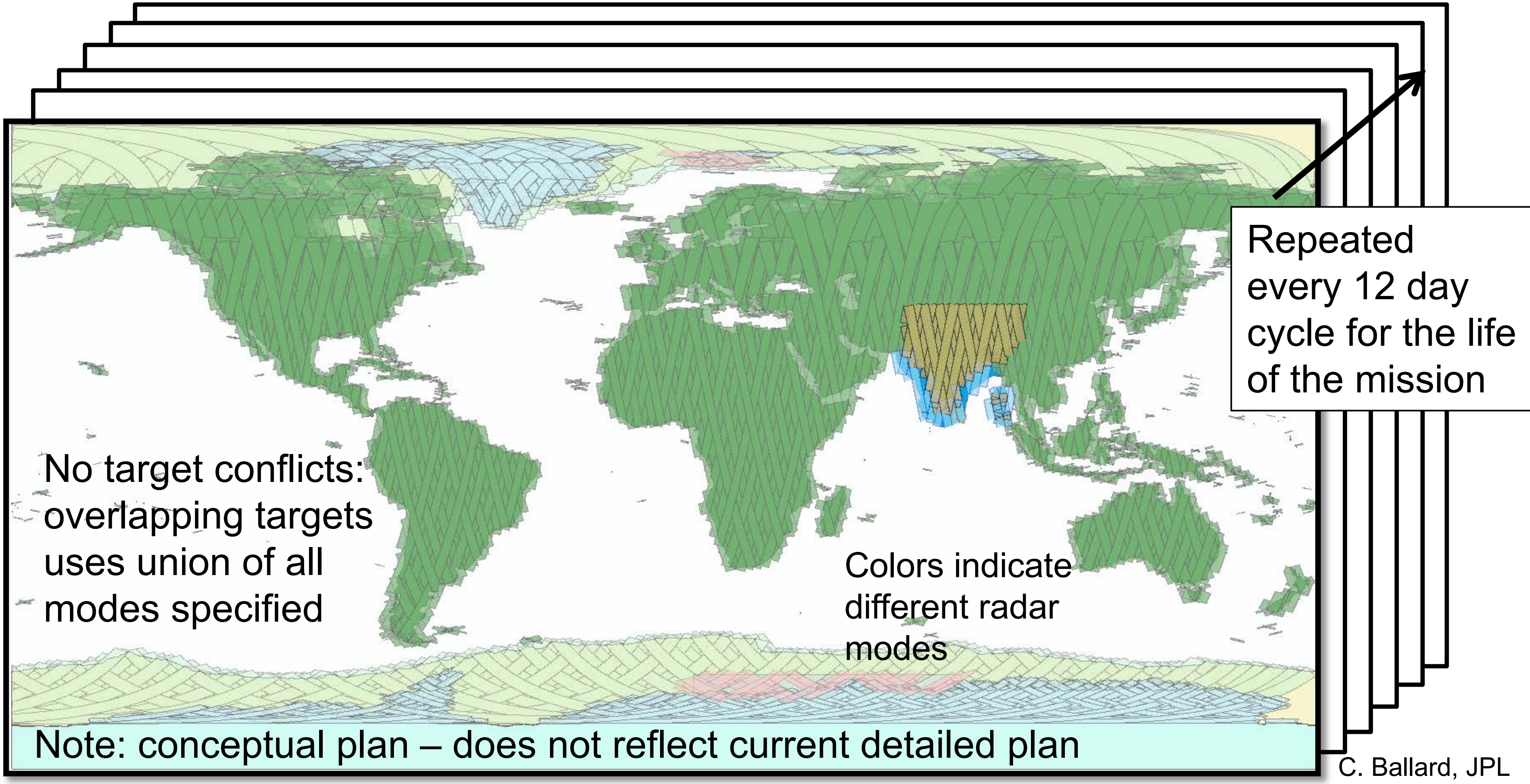
12-day Observation Plan

- Coverage movie Cycle_07 = January, right
- Greenland mosaic (orange), gaps to be filled in subsequent cycle
- SP observations (odd cycle)(brown)
- Urban areas, streaks of non-coverage from culling 2nd & 3rd days
- 80 MHz SP half-swath mode for Ice Sheets illustrated here as full-swath

Background land LSAR 20+5 MHz DP
Land Ice LSAR 80 MHz SP half swath
Sea Ice LSAR 5 MHz SP
ISRO Sea Ice LSAR 20+5 MHz DP; SSAR 25 MHz CP only descending
Urban areas LSAR 40+5 MHz DP
Agriculture LSAR 40+5 MHz QP
ISRO Agriculture LSAR 40+5 MHz QP; SSAR 25 MHZ QP only descending
Low Data rate study mode single pol LSAR 20+5 MHz SP
Agriculture/Sea Ice SSAR CP RH/RV 25
Systematic coverage LSAR 20+5 MHz DP; SSAR 25 MHz RH/RV CP
High resolution deformation (Disaster/urgent response) LSAR 40+5 MHz DP; SSAR SP HH (or SP VV)75 MH
Systematic Coverage and Deformation LSAR DP 20+5 MHz; SSAR DP 37.5 MHz
Ocean LSAR SP VV 5 MHz; SSAR DP VV/VH 10 MHz

NISAR Systematic Observations

L-band globally – S-band regionally

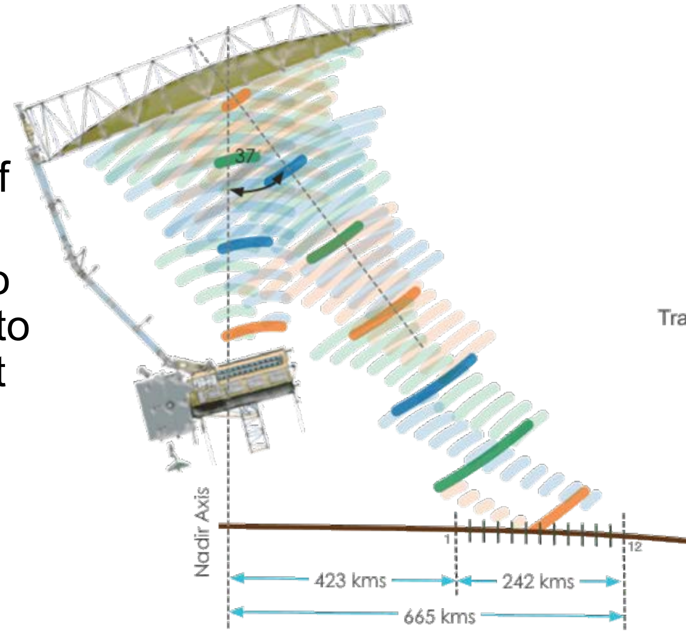


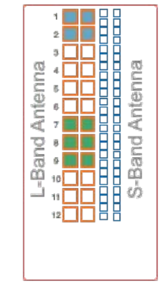
Persistent updated measurements of Earth

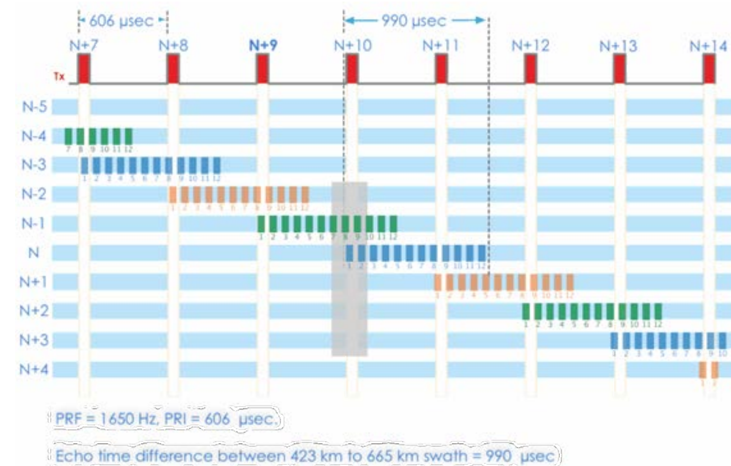
Global Raw data, Images, Interferometry and Polarimetry Products (50 PB)

Measurement Technique
Instrument Concept

- **SweepSAR**
  - On Transmit, illuminate the entire swath of interest (red beam)
  - On Receive, steer the beam in fast time to follow the angle of the echo coming back to maximize the SNR of the signal and reject range ambiguities
  - Allows echo to span more than 1 Inter-Pulse Period (IPP)
- **Consequences**
  - 4 echoes can be simultaneously returning to the radar from 4 different angles in 4 different groups of antenna beams
  - Each echo needs to be sampled, filtered, beam-formed, further filtered, and compressed
  - On-board processing is not reversible – Requires on-board calibration before data is combined to achieve optimum performance

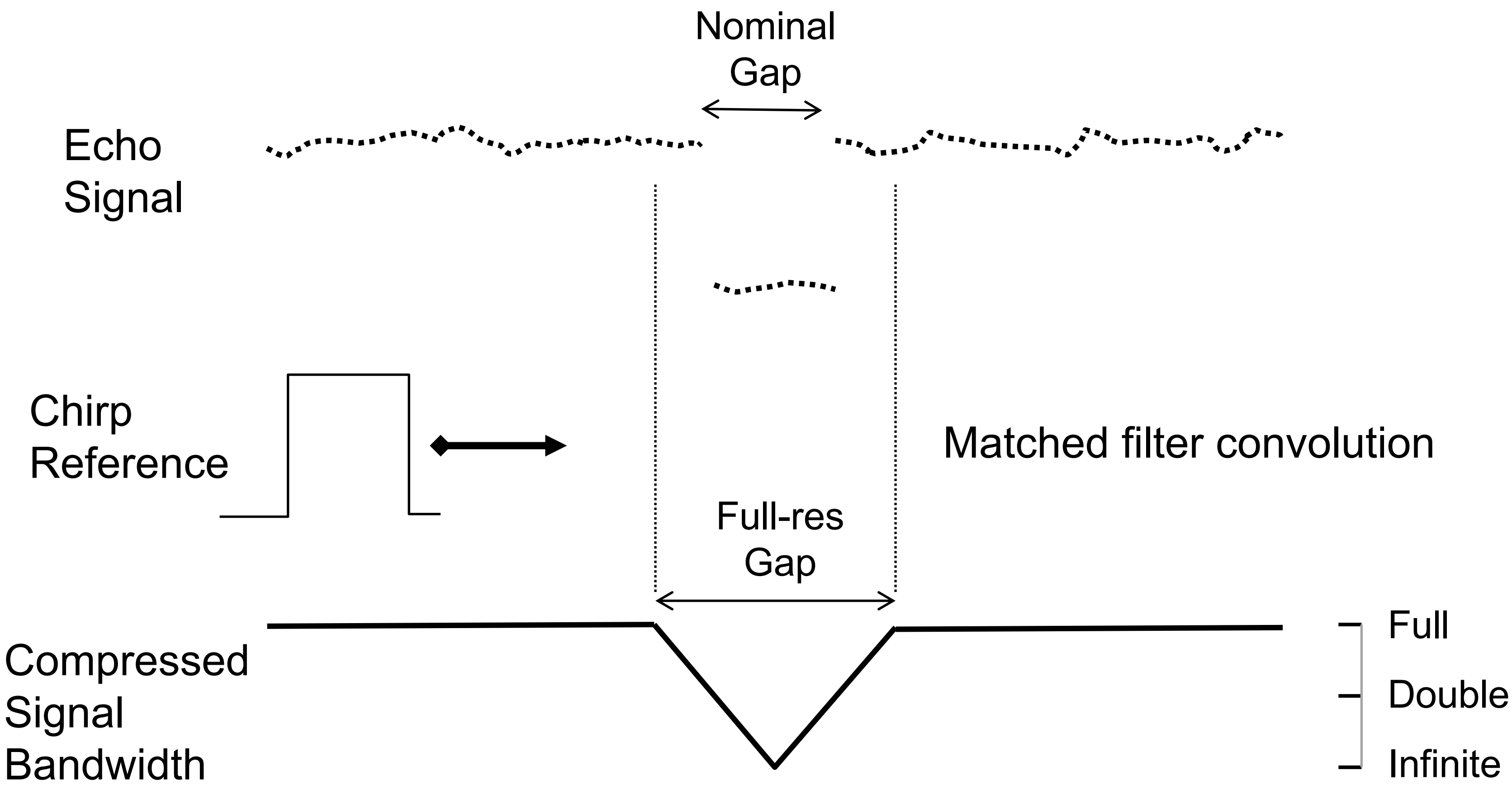






NISAR Receive Blanking Gaps

Gaps versus resolution



NISAR Receive Blanking Gaps

Fixed PRF Operational Characteristics

- NISAR has a fixed set of pulse durations: 5, 20, 25, 40, 45 usecs

Pulse duration (usec)	Gap width in range (km)	Gap width in ground range (near-far) (km)	Gap in Full-res. Obs. (near-far) (km)	Total loss to full-res swath (DP / QP) (km)
5	0.75	1.1-1.4	2.2-2.8	2.2-5.6 / 6.6-11.2
25	3.75	5.6-6.8	11.2-13.6	11.2-27.2 / 33.6-54.4
45	6.75	10.1-12.2	20.2-24.4	20.2-48.8 / 60.6-97.6

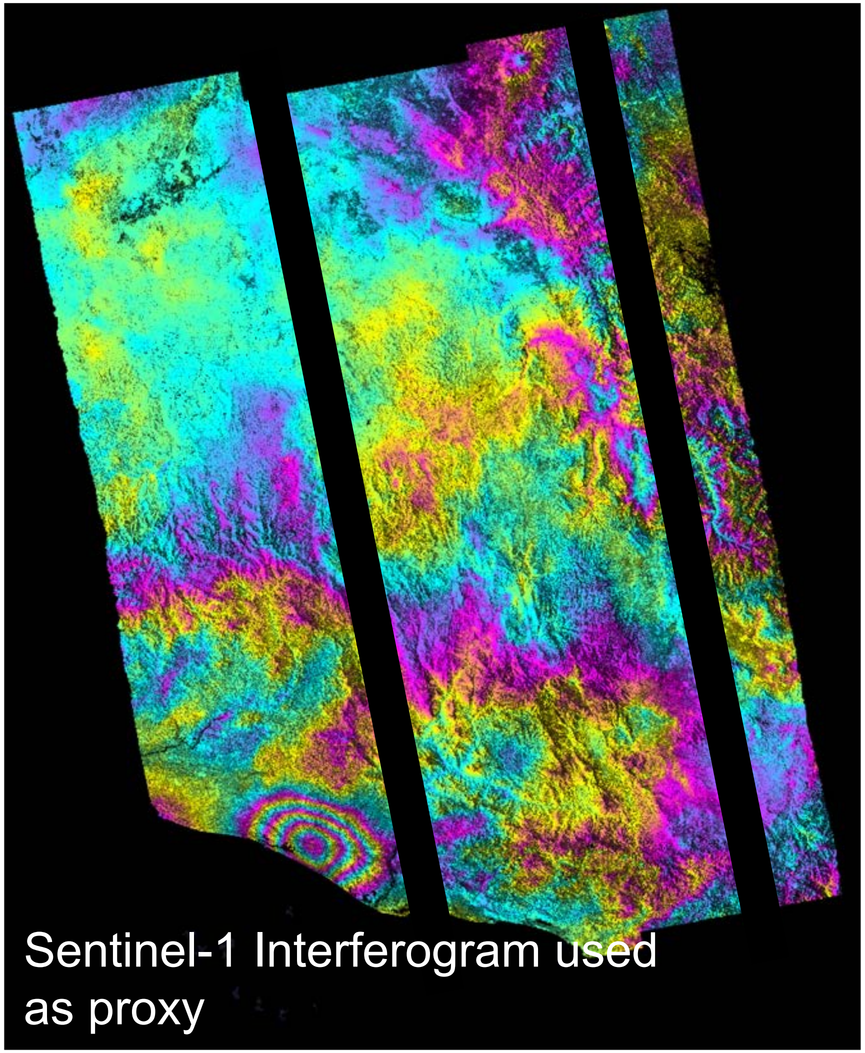
DP – Dual Pol (Single-pol or split-band dual-pol transmit; dual-pol receive)
QP – Quad Pol (H and V transmit on alternate pulses; dual-pol receive)

Image with Gaps

Allows full resolution data only

Assumes

- Fixed PRF
- Background mode
    - 20+5 MHz Dual Pol
    - 2 gaps in swath, each 13.6 km



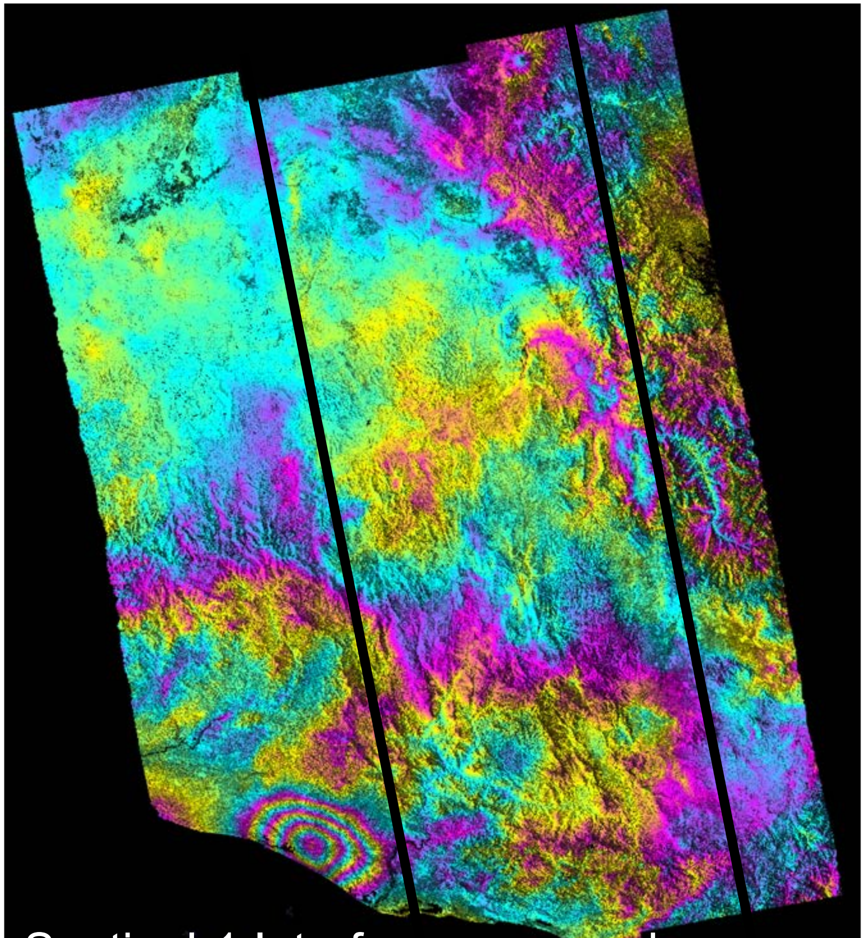
Sentinel-1 Interferogram used as proxy

Image with Gaps

Allows partial resolution data

Assumes

- Fixed PRF
- Background mode
  - 20+5 MHz Dual Pol
  - 2 gaps in swath, each 13.6 km
- ***Use data down to 5 MHz equivalent resolution in gaps***



Sentinel-1 Interferogram used as proxy

Image with Gaps

We always have to deal with gaps…

The swath naturally limits coverage in a broader context

We rely on coverage over time to fill in the globe

Data Acquisition PRF Change

Changing the PRF will shift the location of the gaps

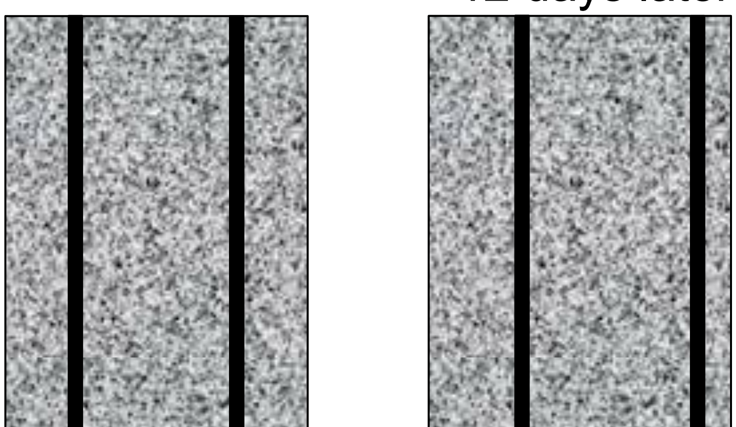
- Gaps occur for ranges, ρ, satisfying the inequality

$$0 \leq \mathrm{mod}\left[\frac{2\rho}{c}, \frac{1}{PRF}\right] \leq \tau$$

- By changing the PRF from one acquisition to the next, all the gaps will be filled with minimal interruption to the time series
- This method can be combined with partial range compression to further ameliorate the overall impact of the image gaps.

12 days later

PRF_1



PRF_2

- Changing PRF changes gap location
- 91 km between pulses
- 3.7 km gaps

➔ 24 cycles to cover areas between pulses

NISAR Solid Earth Science Requirements

Attribute	Secular Deformation (658)	Co-Seismic Deformation (660)	Transient Deformation (663)
Measurement	Spatially averaged relative velocities in two dimensions	Point-to-point relative displacements in two dimensions	Point-to-point relative displacements in two dimensions
Method	Interferometry, Speckle tracking	Interferometry, Speckle tracking	Interferometry, Speckle tracking
Duration	3 years	3 years	Episodic over mission, depending on science target
Product resolution	100 m; smoothed according to distance scale L	100 m	100 m
Accuracy	2 mm/yr or better, 0.1 km < L < 50 km, over > 70% of coverage areas	4 $(1+L^{1/2})$ mm or better, 0.1 km < L < 50 km, over > 70% of coverage areas	3 $(1+ L^{1/2})$ mm or better, 0.1 km < L < 50 km, over > 70% of ~2,000 targeted sites
Sampling	One estimate over 3 years, two directions	4 times per year to guarantee capture of any earthquake on land before surface changes too greatly	Every 12-days, two directions
Coverage	Land areas predicted to move faster than 1 mm/yr	All land, as earthquake locations are unknown *a priori*	Post-seismic events, volcanoes, ground-water, gas, hydrocarbon reservoirs, landslide-prone
Response latency	N/A	24 hour tasking, 5 hour data delivery Best effort basis on event	24/5 Best effort basis on event

NISAR Cryosphere Science Requirements

Attribute	Ice Sheets and Glaciers Velocity Slow Deformation (667)	Ice Sheets and Glaciers Velocity Fast Deformation (668)	Ice Sheet Time-Varying Velocity (738)
Measurement	Point-to-point displacements in two dimensions	Point-to-point displacements in two dimensions	Point-to-point relative horizontal displacements
Method	Interferometry, Speckle tracking	Interferometry, Speckle tracking	Interferometry, Speckle tracking
Duration	3 years	3 years	3 years
Product resolution	100 m	250 m	500 m
Accuracy	3% of the horizontal velocity magnitude plus 1 m/yr, or better, over > 90% of coverage areas	3% of the horizontal velocity magnitude plus 5 m/yr, or better, over > 90% of coverage areas	3% of the horizontal velocity magnitude plus 10 m/yr, or better, over > 80% of coverage areas
Sampling	Each cold season, two directions	Each cold season, two directions	Every 12-days, two directions
Coverage	Areas moving slower than 50 m/yr of both poles and glaciers and icecaps	Areas moving faster than 50 m/yr of both poles	Outlet glaciers, or other areas of seasonal change
Response latency	N/A	N/A	24/5 Best effort basis on event

NISAR Ecosystem Science Requirements

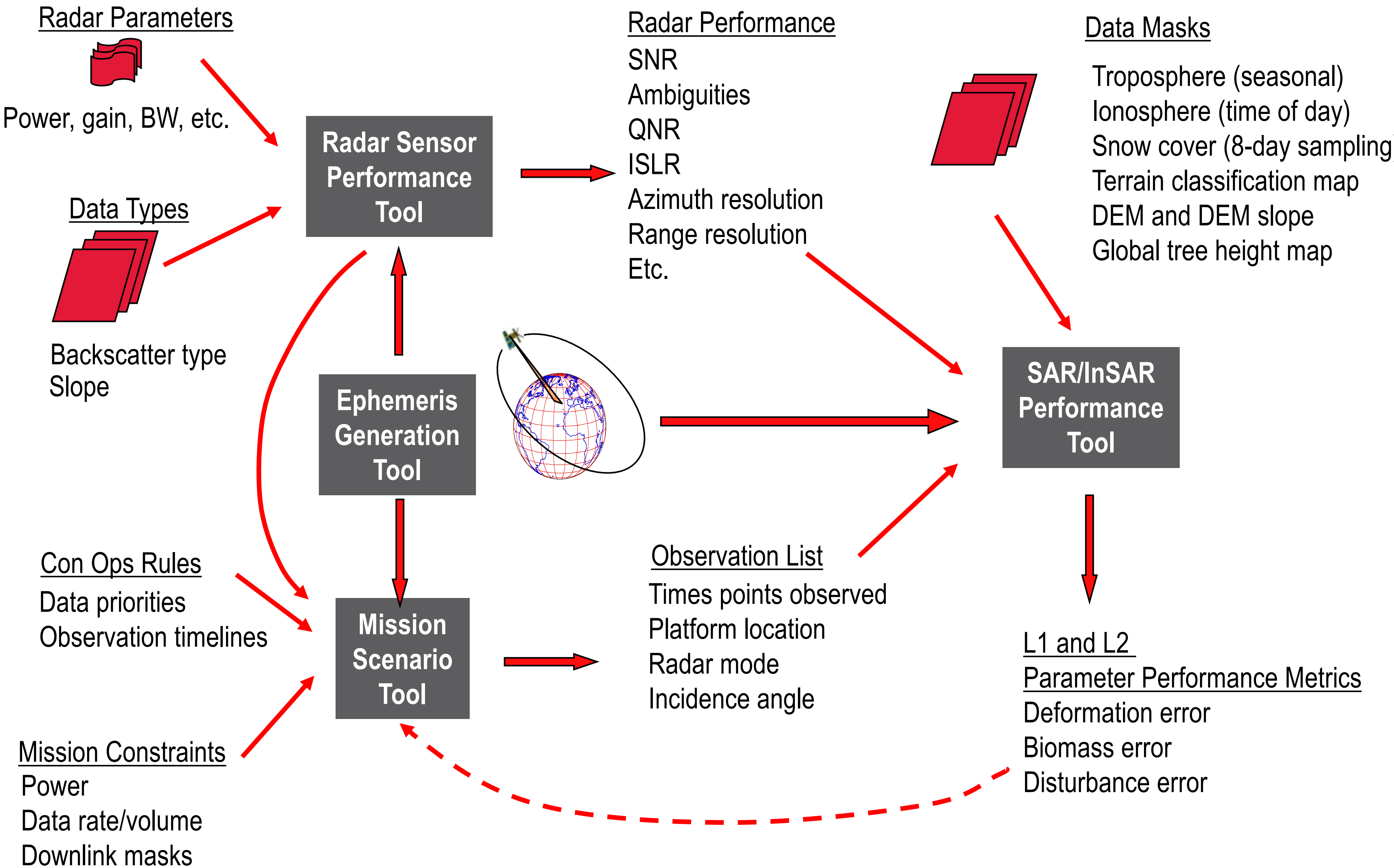
Attribute	Biomass (673)	Disturbance (675)	Inundation (677)	Crop Area (679)
Measurement	Biomass	Areal extent	Areal extent	Areal extent
Method	Polarimetric backscatter to biomass	Polarimetric backscatter temporal change	Polarimetric backscatter contrast	Polarimetric backscatter contrast and temporal change
Duration	3 years	3 years	3 years	3 years
Product resolution	100 m	100 m	100 m	100 m
Accuracy	20 Mg/ha or better where biomass is < 100 Mg/ha, over 80% of coverage areas	80% or better classification accuracy where canopy cover changes by > 50%	80% or better classification accuracy	80% or better classification accuracy
Sampling	Annual	Annual	Seasonal, sampled every 12 days to track beginning and end of flooding events	Quarterly; sampled every 12 days to track beginning and end of growing season
Coverage	Global areas of woody biomass	Global areas of woody biomass	Global inland and coastal wetlands	Global agricultural areas
Response latency	N/A	24/5 Best effort basis on event	24/5 Best effort basis on event	N/A

Imaging Performance ≠ Science Performance

- None of the science requirements rely on *individual image* quality metrics
- Biomass algorithm uses backscatter only and relies on many time samples to address intrinsic environmental variability
  - Filling in gaps is not necessary to meet the requirements
  - Moving the gap by changing the PRF by cycle is acceptable
- Deformation algorithms use time series explicitly, and care about the gaps
  - Phase unwrapping problems
  - The event of interest will occur in the gap by Murphy's law
  - Moving the gap by changing PRF by cycle breaks the time series at any given point at some time in the year
  - However, filling in gaps is not necessary to meet the requirements

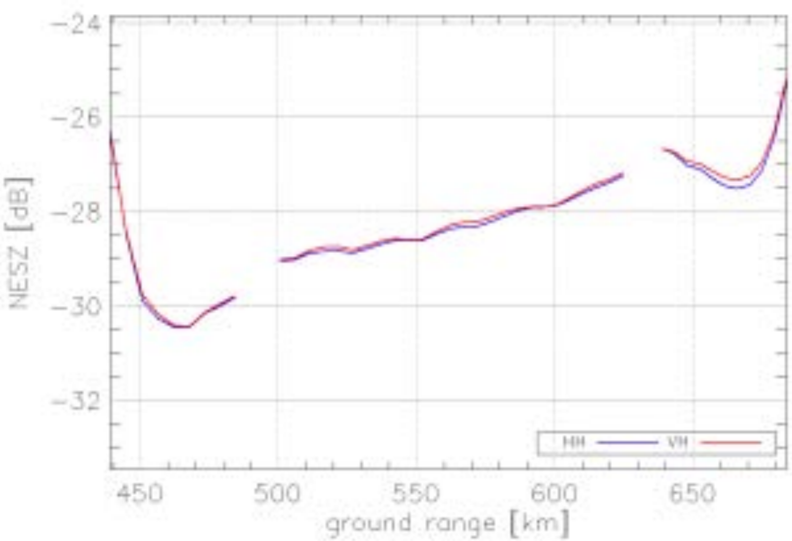
Science Performance Model

Deformation, Biomass, and Disturbance

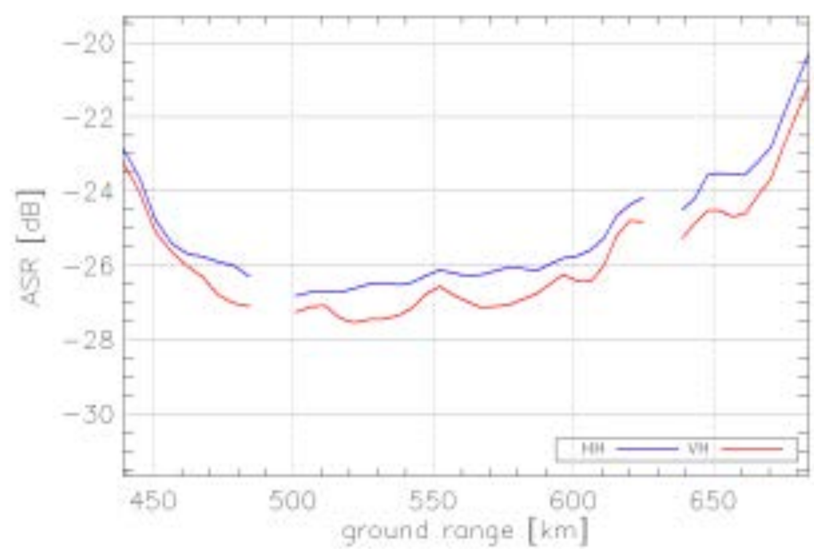


Radar Performance for Nominal Modes

Noise Equivalent Sigma 0

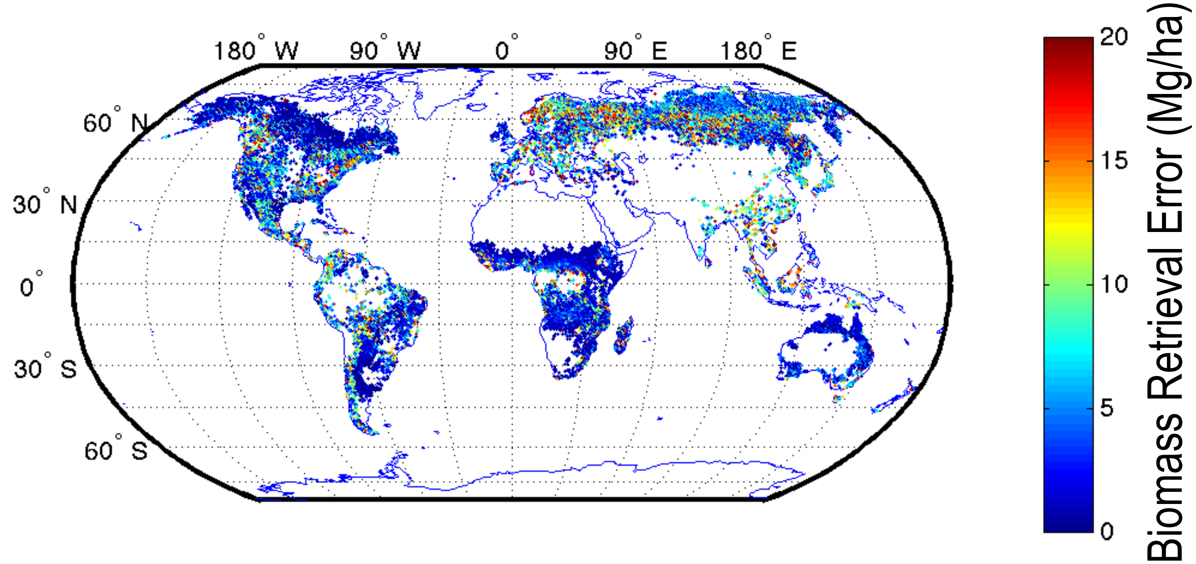


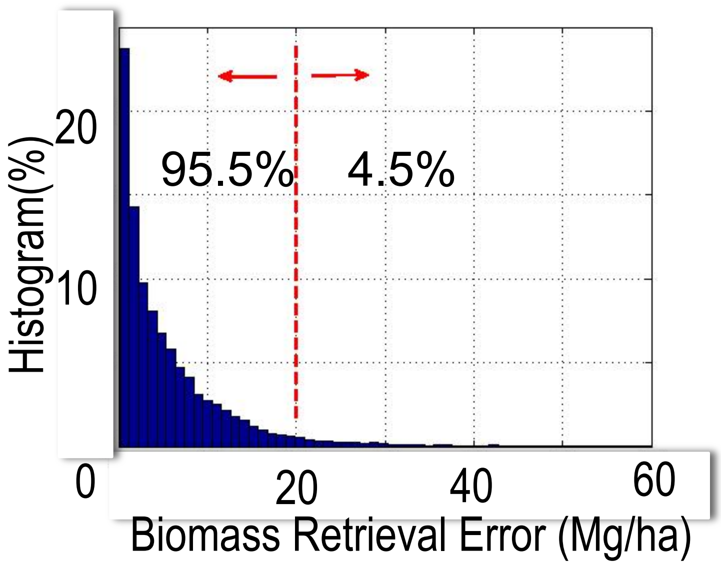
Total Ambiguities



Biomass Performance Summary

Model predicts NISAR meets its biomass requirements





- Points where retrievals were attempted: 27,678
- Points with biomass < 100 Mg/ha: 19,820
- Such points with error < 20 Mg/ha: 18,932
- Percent of such points meeting error threshold: 18,932/19,820 = 95.52% (requirement is 80%)

(Saatchi target map)

Solid Earth Performance Summary

Category	Coverage Req.	Coverage Est.	Uncertainty Req.	Uncertainty Est.	Status
Level 1 in mm	70%	83.0%	3.5 * (1+sqrt(L))	3.00 * (1+sqrt(L))	OK - OK
Coseismic (660) in mm	70%	81.7%	4 * (1+sqrt(L))	3.10 * (1+sqrt(L))	OK - OK
Transients (663) in mm	70%	88.6%	3 * (1+sqrt(L))	2.31 * (1+sqrt(L))	OK - OK
Active (658) in mm/yr	70%	98.1%	2	1.66	OK - OK
PFrost in mm	80%	85.9%	4 * (1+sqrt(L))	2.38 * (1+sqrt(L))	MARGIN-OK

0.1 km < L < 50 km

Meets requirements with > 10% margin

Meets requirements with < 10% margin

Does not meet requirements

Summary

- NISAR will provide dense spatial and temporal coverage globally
  - Systematic, reliable time series for science and applications
- Gaps in swath due to receive blanking affect image completeness, but science requirements can still be met
- Strategies exist to alter PRF from cycle to cycle to fill in coverage gaps, at the cost of creating temporal gaps in time series
- Strategies exist to alter PRF from pulse to pulse to fill in coverage gaps, with trades in image quality performance (see next talk by M. Villano)
- Science team will evaluate optimal strategies for PRF adjustments